

4.—Association of Larger and Planktonic Foraminifera in single samples from Middle Miocene sediments, Guadalcanal, Solomon Islands, southwest Pacific

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Single samples from Miocene sediments in north-central Guadalcanal, Solomon Islands, contain both larger foraminifera and planktonic species of the *Sphaeroidinellopsis seminulina* fauna. This association was contemporaneous during Middle Miocene (Vindobonian) time. *Lepidocyclina* ("Multilepidina") *suvaensis* (Whipple), *Lepidocyclina* (*Nephrolepidina*) *japonica* Yabe, *Cycloclypeus* (*Katacycloclypeus*) *martini* Van der Vlerk and *Miogypsina polymorpha* (Rutten) survived well into the Vindobonian, at least in this part of the Indo-Pacific region.

Introduction

Until a few years ago the age-determination and correlation of Tertiary sediments by means of their foraminifera was based principally on the so-called larger foraminifera with but minor support from the smaller benthonic forms. Over recent years, however, the use of planktonic foraminifera for this purpose has become increasingly common, as might have been expected on purely theoretical grounds, and has been justified in practice. Studies of the planktonic foraminifera, however, are usually made independent of those on larger forms. There are reasons for this—these two groups require different methods of study; more important, sediments containing abundant planktonic species of foraminifera are usually barren of the larger forms, and vice versa, a reflection of their different life environments. This kind of mutual exclusiveness, however, carries with it the risk that age-determinations and correlations based on the one group will differ from those based on the other (see Cole, Todd and Johnson 1960; Glaessner 1960)—a situation which has been common enough in applied palaeontology. The chance of such conflict can be reduced if a sufficient number of mutual occurrences, of stratigraphically defined normal associations, can be established. This paper attempts to provide one such link between larger and planktonic foraminifera which will be applicable to Miocene foraminiferal faunas, at least in the Indo-Pacific region.

Larger foraminifera of the Solomon Islands have been described by Coleman (1963a), and the planktonic forms by McTavish (1963). In the Solomon Islands sediments, as elsewhere, the two groups are not usually found together in the same formation much less in the same

sample. There are two localities, however, in which both have been found together in single samples and a third where samples bearing planktonic forms are only 50 feet stratigraphically above those with larger foraminifera, in strata making up an uninterrupted succession of rapidly-deposited sediments. The first of these, from Middle Miocene sediments in the Tangaraisu River, north-central Guadalcanal, provided the material for this paper. The others are in Aquitanian (Tertiary upper 'e') sediments on San Cristoval and San Jorge, respectively, where there are associations of *Eulepidina ehippioides*, *Spiroclypeus leupoldi*, *Heterostegina borneensis*, *Miogypsina thecideaformis*, *Miogypsinoidea dehaartii* and *Cycloclypeus eidae* with *Globigerina bollii*, *G. (Globigerinita) dissimilis*, *G. (G) unicava*, *Globigerinoides quadrilobatus*, *Globoquadrina dehiscens* and *G. venezuelana*; these Aquitanian associations are to be described in another paper.

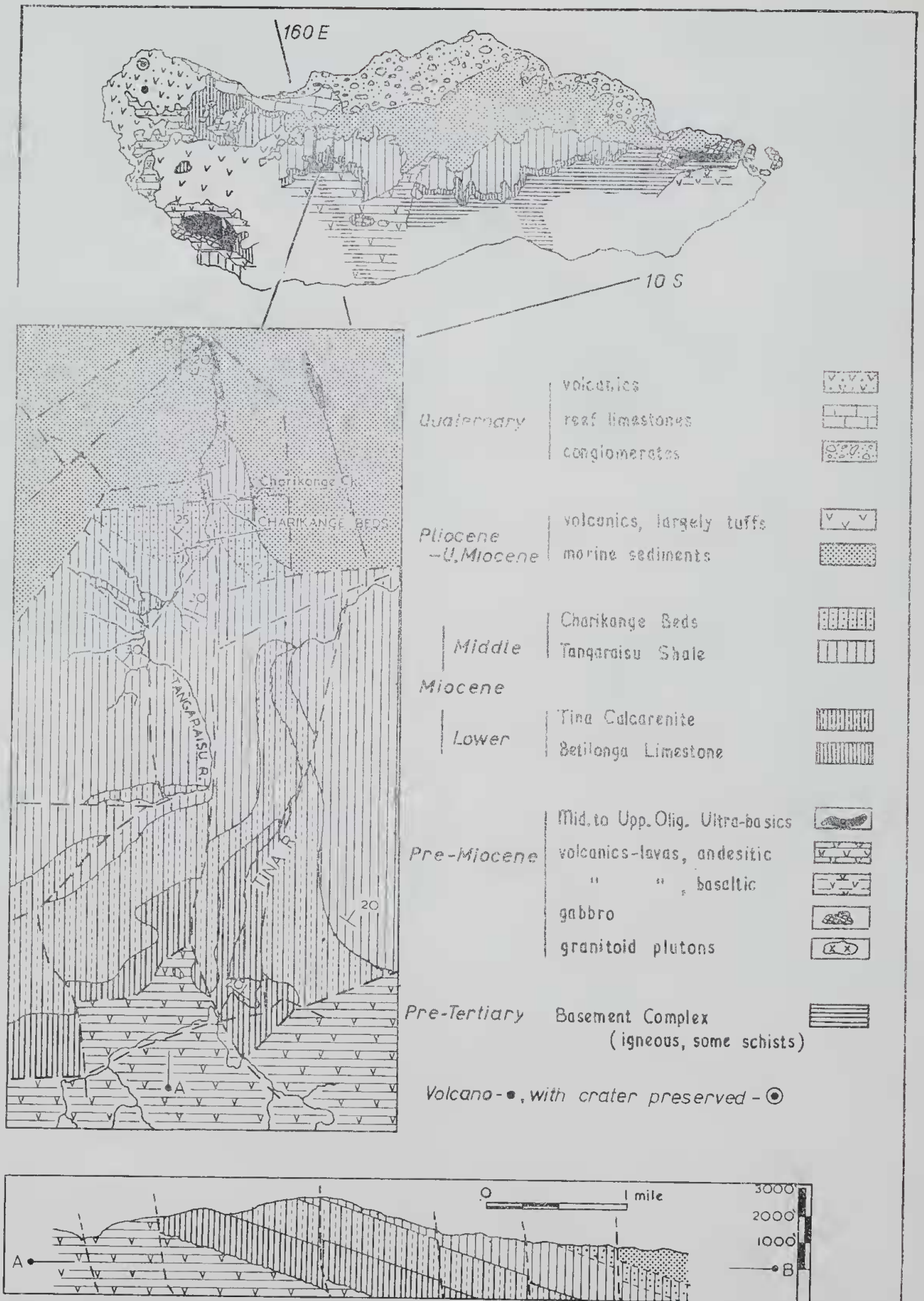
Stratigraphical Background

A traverse along the middle and upper reaches of the Tangaraisu River gives the most complete and least faulted section yet found in north-central Guadalcanal, although faults are still frequent. The sedimentary part of this section was closely sampled by Coleman in 1961. Three of the samples contained both planktonic and larger and small benthonic species of foraminifera.

The geology of the general area was described by Coleman (1960). Figure 1 shows a map and section of the Tangaraisu River area, based on additional fieldwork, and also a general map of Guadalcanal taken, with slight modification, from the first regional geological map of the British Solomon Islands (Coleman 1963b; Coleman *et. al.* 1963). The Miocene sedimentary succession begins with the Betilonga Limestone, a fringing-reef formation about 1200 feet thick. At the base it has a foraminiferal fauna indicating an Aquitanian age, with *Eulepidina*, *Spiroclypeus*, *Miogypsinoidea dehaartii*, *Heterostegina borneensis* and *Cycloclypeus eidae*. At the top it becomes finer grained, lacks reef characteristics, and grades into the overlying Tina Calcarenite which has a fauna more typically Burdigalian. It includes *Lepidocyclina* (*Nephrolepidina*) *martini*, *L. (N.) radiata*, *L. (N.) ferreroi* and *Miogypsina polymorpha*. The Tina Calcarenite is a medium to fine-grained sediment, coarsely bedded with a minor terrigenous content of unaltered ferromagnesian and feld-

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spathic grains derived from the andesitic basement; it is about 1,400 feet thick. It contains abundant planktonic as well as larger foraminifera but the former could not be extracted for identification. Towards the top it is marked by shaley partings which, over a short vertical distance, become predominant to form the base of the Tangaraisu Shale. This is at least 2,000 feet thick, is argillaceous and finely bedded for the most part, but includes many bands of fine-grained lithic volcanic sandstone and occasional conglomerate beds. Near the top of the formation the sediment becomes generally coarse-grained to form the Charikange Beds, a minor unit about 500 feet thick. These beds are banded but poorly bedded, show a good deal of lithological variation and include intraformational structures such as cross-bedding, graded bedding, minor slump folds and displaced small blocks. The banding is due to alternations in grain size and in the proportion of shell fragments. The samples to be described come from near the base of the Charikange Beds. The remainder of the sedimentary succession is made up of the Toni Beds and Mt. Austen Beds, of Pliocene age, and the Honiara Beds of Quaternary age. These consist of organogenic and volcanic or volcanically-derived sediments.

In this part of Guadalcanal, therefore, the sedimentary sequence from basement to the top of the Charikange Beds is about 4,700 feet thick; it shows a regular progression from reef to deeper water sediments with increasing terrigenous content and without evidence of a sedimentary hiatus. The younger sediments were deposited rapidly in fault-bounded troughs and derived from an andesitic terrain which was being uplifted and eroded rapidly. The Charikange Beds mark a time of acceleration in this action.

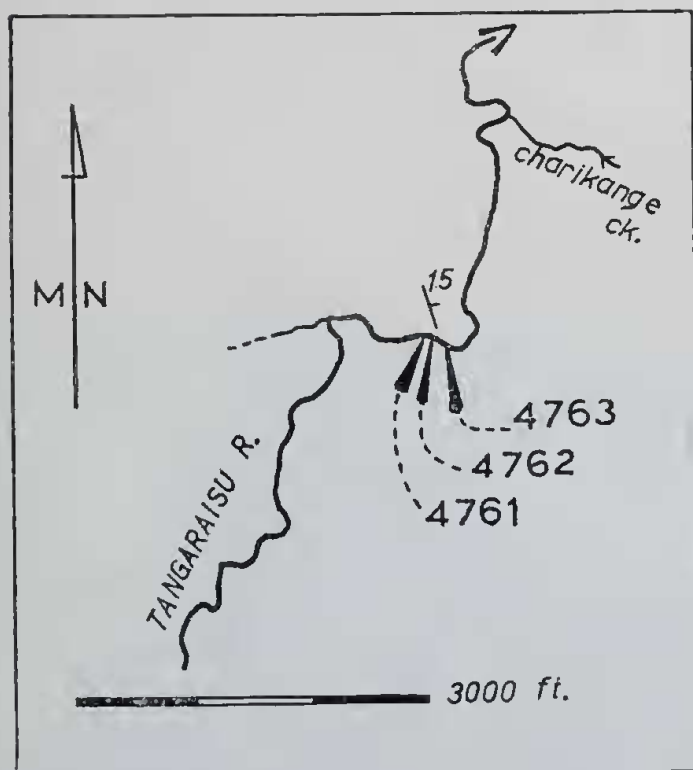


Fig. 2.—Locality map of samples 4761, 4762 and 4763 from the Charikange Beds, Tangaraisu River, north-central Guadalcanal.

Description of the Samples

The samples have British Solomon Islands Geological Survey collection numbers 4761, 4762, and 4763, respectively; splits of them have been retained by that Survey. They were taken from an unfaulted cliff face, at about 80 feet vertical intervals, approximately 550 yards upstream from the junction of Charikange Creek and the Tangaraisu River. The locality is shown in Figure 2. Its co-ordinates on the 1,000 metre Southern New Guinea Zone British Metric Grid, Bessel Spheroid, are 4102650/810620, eastings first.

The grain size in the samples ranges from interstitial clay to rare rock fragments several centimetres across. The larger grains are usually of the order of 2-5 mm across and include larger foraminifera, shell fragments, fragments of andesite and occasional basaltic rocks (mostly lava types), dioritic rocks and, especially important, eroded fragments of Tina Calcarenite and Betilonga Limestone; of these two, the latter is the most frequently represented. The rock fragments are subangular to angular. The mineral content consists of organic calcite, hornblende, plagioclase (andesine-labradorite), hypersthene, epidote, clinopyroxene, chlorite, mica and quartz in that order of abundance. The grains are fresh and many are euhedral. Organic calcite varies from 30% to 60% of the total weight. The cement is calcareous, usually crystalline, but it may be in the form of clay. Size analyses were made of two of the samples, 4761 and 4763. The former had a tenacious calcite cement and could be disaggregated only after treatment with hydrochloric acid. The sample was a large block which included part of a coarse band and part of an underlying fine band. Each portion was analysed separately, the coarse part being 4761A, the fine part 4761B. Sample 4763 was broken down with considerable difficulty, and to judge the effect on the sorting of the foraminifera and other organic calcite, it was examined in its original state (4763A) and after treatment with hydrochloric acid (4763B). The resultant distribution curves are shown in Figure 3. The coarse part of 4761 is poorly sorted whereas the fine part is well sorted. Sample 4763 is moderately sorted although the acid-treated part (4763B) shows that the removal of organic calcite improves the sorting. This effect is confirmed by qualitative examination of the larger foraminifera present in the untreated part of the sample; they range in random fashion from clearly immature small specimens, to large mature specimens. The results of these analyses are not very significant, but they do support the idea, deduced from a variety of other evidence, especially field evidence, that the Charikange Beds were deposited under swiftly varying conditions and that they are turbidites, at least in part. A more formal attempt to determine the processes of deposition of these beds, using the CM patterns of Passega (1957), had to be abandoned because most of the samples could not be broken down without the use of hydrochloric acid, and this destroyed the large and vital fraction made up of transported coarse shell fragments and other organic grains.

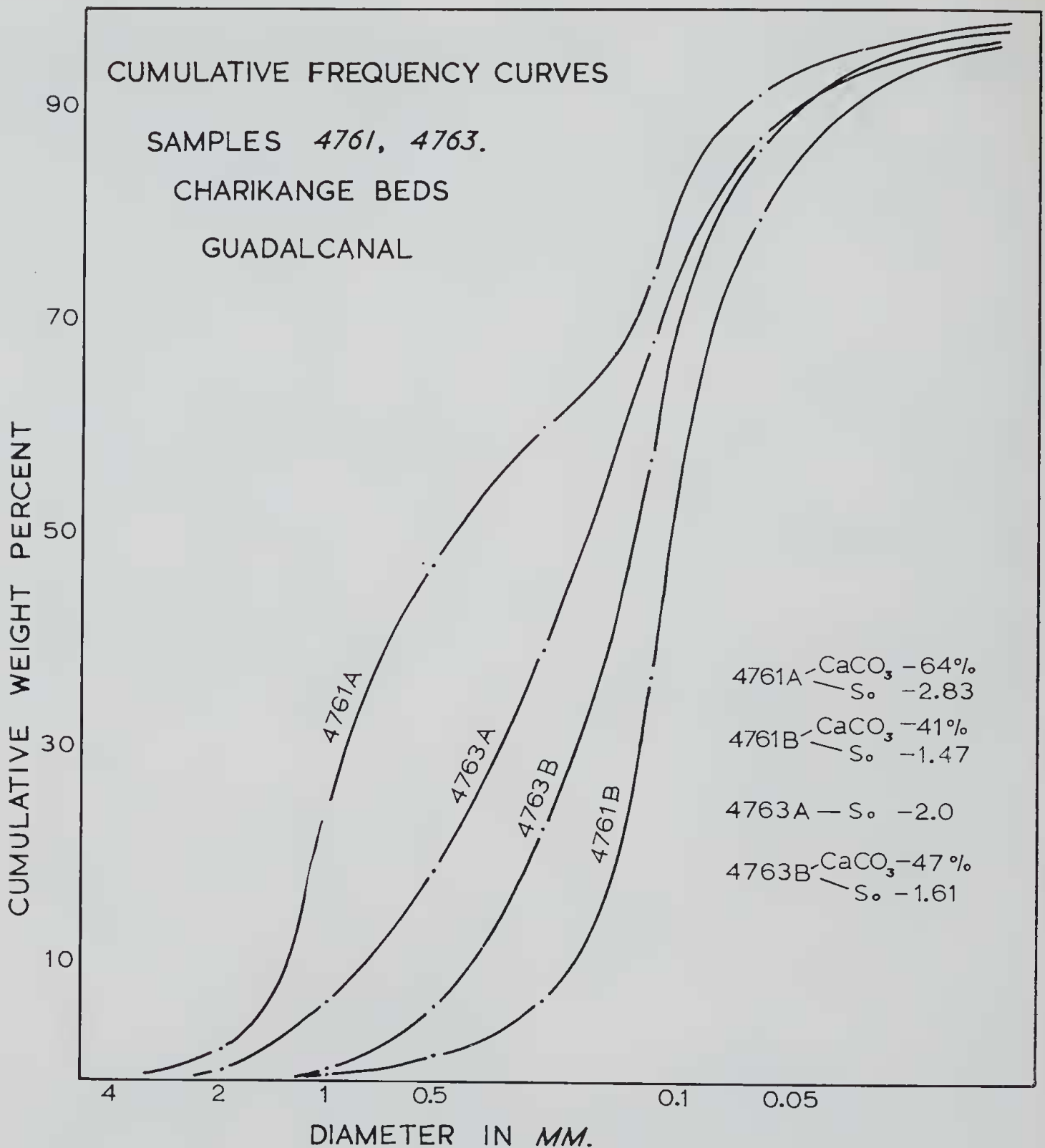


Fig. 3.

The larger foraminifera include both original specimens and those derived from the underlying Tina Calcarenite and the Betilonga Limestone. The latter are easily distinguished. They always have at least a partial coating of crystalline limestone; they are worn, frequently broken, and have a distinctive crystalline infilling. The remaining specimens are considered to be indigenous to the sediment for the following reasons: they are often well preserved so that those with flanges or delicate surface ornament

are entire, contrasting with the shattered shells of most of the small molluscan species; they show a spread in sizes; some are partially air-filled and where infilling is present it is a yellowish clay, the same as that found in many of the smaller specimens, including the planktonic ones; the adherent matrix is common to the sediment. Finally, these indigenous larger foraminifera belong to species of *Lepidocyclina* (including "*Multilepidina*"), *Miogypsina*, *Cycloclypeus* (including subgenus *Katacycloclypeus*),

Planorbulinella, *Gypsina* and *Operculina*, respectively, and so comprise what might be termed a normal fauna. This fauna has not been found in exposures of older sediments on Guadalcanal, even in the underlying older part of the Tangaraisu Shale; in any event this contains the same fauna of planktonic foraminifera as that of the Charikange Beds.

The fauna of smaller benthonic foraminifera was studied to obtain additional evidence on the nature of the original sedimentary environments. Thirty-nine of the sixty-two species of smaller foraminifera have been found also in modern sediments. Thirty-three of these species are benthonic forms, which provide information on the depth and possibly the bottom temperature.

It must be realised, however, that this kind of evidence has inherent limitations. Firstly, there are huge gaps in our knowledge of the ecological and geographical ranges of the species mentioned due to the inadequacy of the sample coverage of the Indo-Pacific province. Secondly, the concepts of some of the species are by no means clear. Thirdly, in the records of Recent species in the Indo-Pacific no distinction has been made between the occurrences of living and dead specimens. Hence, contamination of live assemblages by displaced dead specimens, which results in mixed death assemblages, cannot easily be recognised. Finally, many of the bathyal records might report displaced occurrences which cannot be confirmed and so the shallower occurrences are considered more reliable indices of the living environment of a species.

The following extant benthonic foraminifera are found in the Charikange Beds:

- Amphicoryna scalaris* (Batsch), 1791.
- Amphistegina lessonii* d'Orbigny, 1826.
- Anomalinaella rostrata* (Brady), 1881.
- Bathysiphon fusca* Cushman, 1927.
- Bolivina hantkeniana* Brady, 1881.
- Bolivina schwageriana* Brady, 1881.
- Bulimina inflata* Seguenza, 1862.
- Cassidulina subglobosa* Brady, 1884.
- Cassidulina pacifica* Cushman, 1925.
- Ceratobulimina pacifica* Cushman and Harris, 1927.
- Cibicides refulgens* de Montfort, 1808.
- Cymbaloporella tabellaeformis* (Brady), 1884.
- Dentalina communis* (d'Orbigny), 1826.
- Dentalina subemaciata* Parr, 1950.
- Elphidium craticulatum* (Fichtel and Moll), 1798.
- Eponides margaritiferus* (Brady), 1881.
- Eponides praecinctus* (Karrer), 1868.
- Eponides procerus* (Brady), 1881.
- Eponides subornatus* (Cushman), 1921.
- Gyroidinoides neosoldanii* (Brotzen), 1936 (= *Gyroidina soldanii* (d'Orbigny) as used by Brady in 1884).
- Hyalinea bathica* (Gmelin), 1791.
- Islandiella limbata* (Cushman and Hughes), 1925.
- Nodosaria lamulifera* Boomgaard, 1949.
- Nodosaria pauperata* (d'Orbigny), 1846.
- Nodosaria spirostriolata* Cushman, 1917.
- Nonion pompilioides* (Fichtel and Moll), 1798.
- Planulina wuellerstorfi* (Schwager), 1866.
- Rectobolivina bifrons striatula* (Cushman), 1917.
- Rectobolivina columellaris* (Brady), 1881.
- Robulus costatus* (Fichtel and Moll), 1798.
- Robulus orbicularis* (d'Orbigny), 1826.
- Stilostomella abyssorum* (Brady), 1881.
- Stilostomella consobrina* (d'Orbigny), 1846.
- Uvigerina* spp.

Although there are more planktonic than benthonic specimens of foraminifera in the Charikange fauna, the fauna is mixed and so the evidence given by ratios of planktonic: benthonic foraminifera cannot be used to suggest the depth of deposition of the Charikange Beds. Con-

sidered separately, the planktonic species indicate open-sea conditions and possibly deep water with surface temperatures of about 25°-30°C. It could have been that conditions were similar to those off Guadalcanal today.

The benthonic element comprises a mixed fauna, in which species indicative of shallow-water environments are present with species suggestive of deep-water conditions. *Amphistegina lessonii*, *Anomalinaella rostrata*, *Elphidium craticulatum*, *Lepidocyclinidae*, and *Miogypsiniidae* indicate a shallow, warm water population. Further, *E. craticulatum* and *A. rostrata* seem to be common in warm, tropical waters not deeper than 40 fathoms in the Indo-Pacific. Such an assemblage probably represents an environment of similar depth to Polski's (1959) Central Shelf fauna (150-285 feet), but the bottom temperature probably was 20°-25°C.

A deep-water environment is suggested by the species *Cassidulina pacifica*, *Planulina wuellerstorfi*, *Bulimina inflata*, *Gyroidinoides neosoldanii*, *Nonion pompilioides*, *Rectobolivina bifrons striatula*, *Nodosaria spirostriolata*, *Stilostomella abyssorum* and *S. consobrina*. There are only a few depth records available for the last four of these species, all of them for depths of the order of 500 to 700 fathoms. The other five species have been recorded from shallow waters of less than 100 fathoms, but by far the great majority of their records are for depths of 500 fathoms or more. By and large this assemblage of species suggests an original environment roughly corresponding to Polski's Middle Bathyal fauna (2,000-4,500 feet and bottom temperatures of 6°-10°C.). As well, the species *Höglundina elegans* occurs higher in the Charikange Beds and this species has been recorded many times from deep water only.

This faunal evidence at least indicates that the Charikange Beds were formed by mixing of sediments. Marine sediments deposited in a shallow-water tropical environment, along with sediments from intermediate depths, were displaced to a depth of about 500 fathoms by slumping prior to consolidation of any of the sediments. Transportation by turbidity currents would thoroughly mix the sediments from the shallower depths, and these in turn would mix with the deep-water sediments accumulating at their ultimate position of rest.

Conclusions on the Charikange Beds

The combination of evidence afforded by the regional field study and the sedimentary and faunal character of the samples examined, leads us to the following conclusions:

- (1) The Charikange Beds were deposited rapidly in a tectonically unstable environment; the bulk of them are first-cycle sediments.
- (2) Slumping or other transport played a part in the accumulation of the Charikange Beds.
- (3) The association of larger and planktonic foraminifera was not due to the derivation of the former type from older consolidated sediments; it is best explained by contemporaneous transport by slumping or turbidity flow, which

carried natural life-assemblages of warm fairly shallow water benthonic foraminifera and their containing sediments into deeper water. This transport took place long before there was any consolidation of the sediments.

- (4) The association now to be described was essentially contemporaneous.

The Association

The following species of planktonic and larger benthonic foraminifera are found in samples 4761, 4762 and 4763. Qualitative estimates of frequency are given for each species. For the larger forms, if more than 25 specimens could be picked from about 100 gms of sediment the species is said to be abundant (a); if 11-25 specimens, common (c); if 5-10 specimens, frequent (f); if less than 5 specimens, rare (r); and if only one specimen could be picked, very rare (v). For the planktonic forms the same frequency range is based on about 5 gms of sediment.

Larger Foraminifera

	4761	4762	4763
<i>Operculina complanata japonica</i>	a	r	a
<i>Lepidocyclina</i> ("Multilepidina") <i>suvaensis</i>	...	r	a
<i>Operculina renosa</i>	c	f	e
<i>Cyclocypeus</i> (C.) <i>indopacificus</i>	c	f	f
<i>Lepidocyclina</i> (N.) <i>japonica</i>	f	f	r
<i>Miogyopsina polymorpha</i>	f	f	...
<i>Planorbulinella</i> cf. <i>larvata</i>	r	r	r
<i>Cyc.</i> (<i>Katacycloclypeus</i>) <i>martini</i>	r	r	r
<i>Gypsina squamiformis</i>	...	r	v
<i>Lepidocyclina</i> (N.) <i>martini</i>	r	...	...
<i>Planorbulinella</i> sp.	...	...	v
<i>Heterostegina</i> sp.	...	...	v

Planktonic Foraminifera

<i>Globigerinoides conglobatus</i>	...	v	...	r
<i>G. oides obliquus</i>	...	...	...	f
<i>G. oides quadrilobatus immaturus</i>	...	r	f	f
<i>G. oides quadrilobatus succatifer</i>	...	v	v	r
<i>G. oides quadrilobatus trilobus</i>	...	r	...	e
<i>Globobulimina allispica allispica</i>	...	r	...	e
<i>G. imi delhisceus adreana</i>	...	r	...	v
<i>G. imi delhisceus delhisceus</i>	...	r	r	f
<i>Globobulimina scitula</i>	...	...	...	v
<i>G. su. cf. G. lauida</i>	...	f	f	a
<i>Gubulina adreana</i>	...	v	v	r
<i>Polleninina obliquilobata</i>	...	r	r	r
<i>Sphaerulidinetopsis kochi</i>	...	r	...	r
<i>S. scandinavica</i>	...	a	e	a
<i>S. subdelhisceus</i>	...	f	r	e

Notes on the Species

Larger Foraminifera

Lepidocyclina ("Multilepidina") *suvaensis* (Whipple) 1934—Plate 1, Figs. 9-14.

This is the same species as that described by Whipple as *L. (Cyclolepidina) suvaensis* from Fiji. It is found in other parts of the Indo-

Pacific region and is usually considered to be of Burdigalian age. A number of specimens are figured to show variation in the nature of the nucleoconch and the usual presence of rays which can often be seen in equatorial section; this is a feature distinguishing it from otherwise similar species, e.g. *L. ("M.") luxurians* (Tobler) or *L. ("M.") irregularis* (Hanzawa). It should be stressed that the nucleoconch with two large chambers (Fig. 9) is a rare variant. Only two of about 100 specimens are like this; the remainder have from 3 to 7 chambers (the actual number may depend on the precise location of the thin section with respect to the plane of equatorial chambers).

Following the work of Van der Vlerk (1961) the internal features of the type of *L. radiata* (Martin) are now known for the first time. Their resemblance to those of the Guadalcanal specimens is striking as may be seen by a comparison between Van der Vlerk's description and illustrations with those in Coleman 1963a (Plates 3 and 4; note especially Figure 5 on Plate 4), and also the illustrations in this paper. It may well be that the Guadalcanal specimens should be referred to *L. radiata*. This possibility is left standing until more is known of the variation in topotypic specimens of that species. Van der Vlerk considers that the type of *L. radiata* came from sediments younger in age than Burdigalian.

The above remarks contribute to the problem of the significance of multilocular embryonic chambers in *Lepidocyclina*, and as a corollary to this, the concept and validity of *Multilepidina* and *Plielepidina*, respectively (for references, see Cole 1963a and 1963b). Discussion of this problem, however, lies outside the aim of this paper.

Lepidocyclina (Nephrolepidina) japonica Yabe, 1906 — Plate 1, Figs. 7, 8.

On Guadalcanal this species is also found in the Tina Calcarene and the upper part of the Betilnga Limestone, but not in the lower part (of Aquitanian age) as stated previously by Coleman (1963a). Specimens which are clearly derived from these sediments are found in the Charikange Beds together with those considered to be indigenous.

Lepidocyclina (N.) martini (Schlumberger), 1900 — Plate 1, Fig. 1.

The lenticular shape without a marked central boss and the marked elongation of the equatorial chambers along the rays distinguish this species from the otherwise similar *L. (N.) radiata* (Martin) as it is generally conceived. According to Eames et al. (1962) *L. (N.) martini* is a Vindobonian species but it has been found as part of

PLATE 1

1 : *Lepidocyclina (Nephrolepidina) martini* (Schlumberger) Equatorial section of UWA 50411, X20; 2 : *Planorbulinella* sp. cf. *P. larvata* (Parker and Jones) Transverse section of UWA 50412, X32; 3 : ? *Planorbulinella* sp. Median section of UWA 50413, X20; 4, 5 : *Miogyopsina polymorpha* (Ruttan) 4, transverse section of UWA 50414, X25; 5, part-median section of UWA 50415, X20; 6 : *Heterostegina* sp. cf. *H. suborbicularis d'Orbigny* Partial median section of UWA 50416, X30; 7, 8 : *Lepidocyclina (Nephrolepidina) japonica* Yabe 7, vertical section of UWA 50417, X13; 8, equatorial section of UWA 50418, X13; 9-14 : *Lepidocyclina ("Multilepidina") suvaensis* (Whipple) 9, central portion of equatorial section, UWA 50419, X25; 10, vertical section of UWA 50420, X11; 11, central portion of equatorial section, immature specimen, UWA 50421, X19; 12, equatorial section (slightly oblique) of UWA 50422, X19, showing elongation of hexagonal chamberlets along rays; 13, 14, external appearance of UWA 50423, X5, and UWA 50424, X5; 15 : *Cyclocypeus (Cyclolepidina) indopacificus* Tan Median section of UWA 50425, X13; 16-17 : *Cyclocypeus (Katacycloclypeus) martini* Van der Vlerk 16, median section of UWA 50426, X12; 17, external appearance of broken specimen, UWA 50427, X4.5; 18-20 : *Operculina complanata (DeFrance) japonica* Hanzawa 18, external appearance of UWA 50428, X5; 19, median section of UWA 50429, X12; 20, median section of UWA 50430, X12, a more tightly coiled specimen.

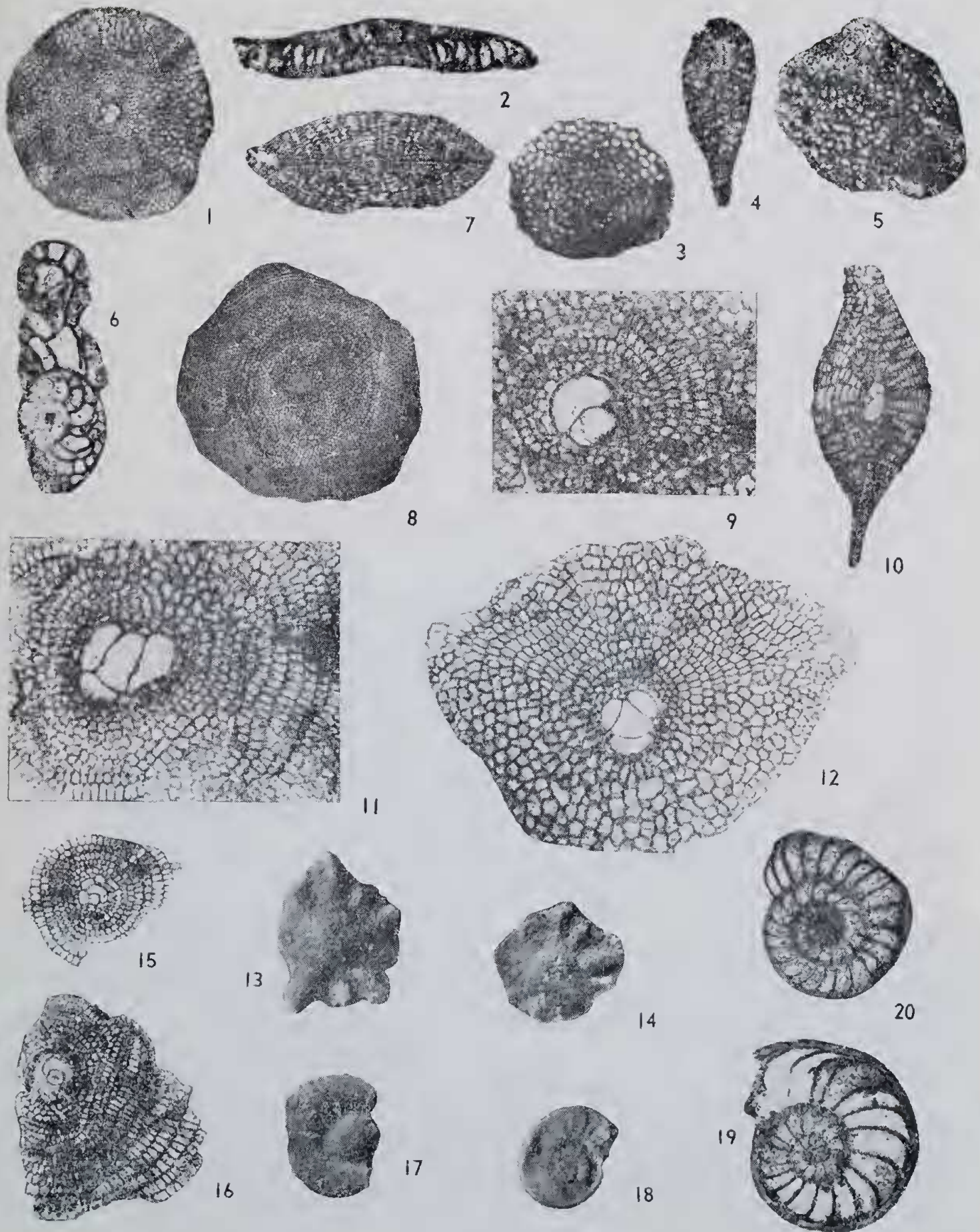


Plate 1

typically Burdigalian assemblages (Coleman 1963a) in the Tina Calcarene, the Bonege Limestone, the Lake Lee Calcarene (Guadalcanal) and the Anuha Calcarene (Florida).

Miogyssina polymorpha (Rutten), 1911 — Plate 1, Figs. 4, 5.

Specimens of this species derived from the upper part of the Betilonga Limestone are also found together with indigenous specimens. They cannot be distinguished morphologically.

Cycloclypeus (Cycloclypens) indopacificus Tan, 1932 — Plate 1, Fig. 15.

This species is common in the Indo-Pacific region in sediments of Vindobonian age, but it occurs also in Burdigalian sediments on Guadalcanal (Bonege Limestone, Lake Lee Calcarene) on Florida (Anuha Calcarene) and also on Fiji (in the "Lepidocyclina Tuff", see Eames *et al.* 1957).

C. (Katacycloclypeus) martini Van der Vlerk, 1923 — Plate 1, Figs. 16, 17.

Species of this subgenus are characteristic of the Burdigalian. It has not been recognised with certainty from other Solomon Islands sediments.

Operculina complanata japonica Hanzawa, 1935 — Plate 1, Figs. 18-20.

Specimens of this subspecies show great variation, the extremes of which are connected by a continuous series of intergrading specimens. It is present in flood proportions in the Charikange Beds but is rare in other Solomon Islands sediments of about the same age.

O. venosa (Fichtel and Moll), 1798.

Probably the most common species found in Solomon Islands Tertiary and Quaternary sediments, *O. venosa* is also present in great numbers in the present-day beach sands. The oldest specimens do not appear to be in any way different from the modern ones.

Planorbulinella sp. cf. *larvata* (Parker and Jones), 1865 — Plate 1, Fig. 2.

Although referred to *P. larvata* this is almost certainly a new species having as its major distinguishing feature a laminated central portion; the laminations are the result of lateral extensions of the chamber walls (see Coleman, 1963a) and do not appear to represent a gerontic feature. It is especially characteristic of Burdigalian to Quaternary sediments in the Solomon Islands.

Planorbulinella sp. — Plate 1, Fig. 3.

This rare species has been seen in thin sections of the Charikange samples.

Gypsina squamiformis Chapman, 1900.

The Moluccan form described under this name by Bursch (1947) also occurs in the Charikange samples.

Heterostegina sp. — Plate 1, Fig. 6.

Only two specimens of this species have been seen, both in thin section. Its features are not sufficiently clear to permit a specific identification but it could well be *H. suborbicularis* d'Orbigny, a Pacific region Quaternary species. Cole (1957) records it from Eocene sediments from Eniwetok Atoll.

Planctonic Foraminifera

Globigerinoides conglobatus (Brady), 1879 — Plate 2, Figs. 15, 16, 21.

One poorly preserved specimen seems to belong here. Banner and Blow (1960) gave the range of *G. conglobatus* as Pliocene to Recent, and they pointed out that certain Eocene and Lower Miocene records attributed to *G. conglobatus* are of other species. Belford (1962) recorded this species from the Upper Miocene of Papua-New Guinea, and Umbgrove (1931, p. 63) listed it from Miocene 'f' to Recent of Indonesia.

This species is most abundant in the equatorial part of the Pacific, in waters ranging from 16°C. to 33°C. (Bradshaw 1959). In the Indian Ocean it is present in the central and equatorial water masses (Beliaeva 1962), where the surface water temperatures range from 10°C. to 28°C.

Globigerinoides obliquus Bolli, 1957 — Plate 2, Figs. 10, 17.

This species is rare in the Charikange Beds. The absolute range recorded for this species in the Caribbean region is from the *Globorotalia kugleri* zone (Upper Oligocene) to the *Globigerina bulloides* zone of Upper Miocene age (Bolli 1957; Blow 1959). Belford (1962) has rare specimens from the Middle Miocene of Papua. Its range in the Solomon Islands is from Upper Oligocene to Upper Miocene-Pliocene.

Globigerinoides quadrilobatus immaturus (LeRoy), 1939 — Plate 2, Figs. 11, 18.

This subspecies can be distinguished from *G. quadrilobatus trilobus* (Reuss) by its more highly arched umbilical aperture and the less embracing ultimate chamber although transitional forms are difficult to place with certainty. In

PLATE 2

1 : *Sphaeroidinellopsis subdehiscens* (Blow) Umbilical view, UWA 49146, X75; 2-4 : ? *Pulleniatina obliquiloculata* (Parker and Jones) 2, lateral view; 3, umbilical view; 4, dorsal view; UWA 49149, X75; 5, 8 : *Sphaeroidinellopsis seminulina* (Schwager) 5, umbilical view of *multiloba*-type, UWA 49159, X60; 8, umbilical view of typical form, UWA 49147, X60; 6, 13, 14 : *Globoquadrina dehiscens advena* Bermudez 6, lateral view; 13, dorsal view; 14, umbilical view; UWA 49143, X60; 7, 9 : *Globigerinoides quadrilobatus trilobus* (Reuss) 7, dorsal view; 9, umbilical view; UWA 49139, X75; 10, 17 : *Globigerinoides obliquus* Bolli 10, umbilical view; 17, dorsal view; UWA 49141, X100; 11-18 : *Globigerinoides quadrilobatus immaturus* (LeRoy) 11, umbilical view; 18, dorsal view; UWA 49137, X75; 12, 19 : *Globoquadrina dehiscens dehiscens* (Chapman, Parr and Collins) 12, umbilical view; 19, dorsal view; UWA 49144, X60; 15, 16, 21 : *Globigerinoides conglobatus* (Brady) 15, umbilical view; 16, dorsal view; 21, lateral view, UWA 49140, X60; 20, 23, 24 : *Globoquadrina altispira altispira* (Cushman and Jarvis) 20, umbilical view; 23, lateral view; 24, dorsal view; UWA 49142, X75; 22 : *Orbulina universa* d'Orbigny UWA 49145, X50; 25, 26, 30 : *Sphaeroidinellopsis kochi* (Caudri) 25, dorsal view; 26, umbilical view; 30, lateral view; UWA 49148, X60; 27, 31-33, 37, 38 : *Globorotalia* cf. *G. tumida* (Brady) 27, lateral view; 31, umbilical view; 32, dorsal view; UWA 49136b, X75; 33, lateral view; 37, dorsal view; 38, umbilical view; UWA 49136a, X100; 28, 28 : *Globigerinoides quadrilobatus sacculifer* (Brady) 28, umbilical view; 29, dorsal view; UWA 49138, X75; 34-36 : *Globorotalia scitula* (Brady) 34, umbilical view; 35, dorsal view; 36, lateral view; UWA 49094, X60.



Plate 2

the Solomons this subspecies ranges from the Aquitanian to the Upper Miocene-Pliocene, but previous records from the Indo-Pacific region extend its range into the Upper Oligocene.

Globigerinoides quadrilobatus sacculifer (Brady), 1877 — Plate 2, Figs. 28, 29.

The specimens from the Charikange fauna are most like the lectotype of *G. quadrilobatus sacculifer* chosen by Banner and Blow (1960). Although a transitional series between *G. quadrilobatus irregularis* LeRoy and this subspecies could be recognised in the Charikange fauna, no attempt was made to separate these subspecies in this work.

This cosmopolitan species is well represented in Neogene to Recent sediments of the Indo-Pacific region (Umbgrove 1931; LeRoy 1941; Crespín 1963; Chang 1959; Belford 1962). Bradshaw (1959) found it in Pacific waters ranging in surface temperature from 15°C. to 33°C., but it was most common between 25°C. and 29°C. In the Indian Ocean it is present in the tropical and central parts with a temperature range of 10°C.—28°C., according to Beliaeva (1962).

Globigerinoides quadrilobatus trilobus (Reuss), 1850 — Plate 2, Figs. 7, 9.

This subspecies of *G. quadrilobatus* has been separated from *G. quadrilobatus immaturus* by characters of its final chamber, which is more inflated and more embracing, and by the more elongate, narrower primary aperture. A cosmopolitan subspecies, *G. quadrilobatus trilobus* first appeared in the Lower Miocene and has persisted to the present. It has been widely recorded from the Indo-Pacific region.

Globoquadrina altispira altispira (Cushman and Jarvis), 1936 — Plate 2, Figs. 20, 23, 24.

Although the poor preservation of specimens assigned to *Globoquadrina* has destroyed or obscured details of the umbilical teeth which especially distinguish this genus, the specimens possess other features of the test which characterise known specimens of *Globoquadrina*, in particular *G. altispira altispira*.

This species is distinguished from *G. dehiscens dehiscens* by its high trochoid spire and the axially elongate chambers; an otherwise similar subspecies, *G. altispira globosa*, has globular and less elongate chambers in the last whorl. Although previous records indicate that *G. altispira altispira* became extinct late in the Burdigalian or early in the Helvetian, Chang's (1959) Upper Miocene record from Taiwan and Belford's (1962) observation of the species in strata dated as Pliocene from Papua-New Guinea, might be taken as evidence for a markedly longer range for *G. altispira altispira* in the equatorial part of the Indo-Pacific than elsewhere. However, Chang's record is doubtful, because two of his figured specimens (Chang 1959, Plate 2, Figs. 8a-9c) belong to other forms of *Globoquadrina*. Belford's identifications, on the other hand, seem correct but the age determinations of some of his younger faunas may be in error. Although this evidence is equivocal, additional records from Wreck Island (Lloyd 1961) and the Solomons (McTavish 1963) showed that *G. altispira altispira* probably be-

came extinct late in the Tertiary 'f'. It seems likely that the range for this species is Aquitanian to Tortonian.

Globoquadrina dehiscens advena Bermudez, 1949 — Plate 2, Figs. 6, 13, 14.

The range for this subspecies seems to be closely similar to that of *G. altispira altispira* except that it probably became extinct earlier in the Tortonian, as it does in the Solomons.

Globoquadrina dehiscens dehiscens (Chapman, Parr and Collins), 1934 — Plate 2, Figs. 12, 19.

The Charikange specimens generally agree with those figured by Blow (1959) and Jenkins (1960), in which the apertural face is neither as prominent nor as smooth as that of the holotype. The first chamber of one specimen seems to be divided into two, thus giving the appearance of five chambers in the last whorl.

This species is moderately long-ranging with a wide distribution. It ranges from Middle or Upper Oligocene to Upper Miocene, but it is most common in the Lower and Middle Miocene. In the Solomons *G. dehiscens* became extinct in the *Sphaeroidinellopsis seminulina* fauna or Tertiary Upper 'f' age.

Globorotalia scitula (Brady), 1882 — Plate 2, Figs. 34-36.

A single, typical specimen of *G. scitula* has been found in the Charikange fauna. Although the range of *G. scitula (sensu lato)* is Aquitanian to Recent according to Blow (1959), the species is only present in Vindobonian and younger sediments of the British Solomon Islands. It has been found in small numbers over a wide range of temperatures (12°C.—29°C.) in the Pacific (Bradshaw 1959).

Globorotalia sp. cf. *G. tumida* (Brady), 1877 — Plate 2, Figs. 27, 31-33, 37, 38.

This is an extremely variable species, and its variation is much greater than that found in Upper Miocene populations of *G. tumida* from Guadalcanal. The more obvious variation is in the shape of the chambers and the outline of the periphery. However, there is variation in the numbers of chambers in the last whorl, commonly five to seven with eight in rare specimens. Further, there is a range in the convexity of the spiral, but spiro-convex specimens appear to be rare.

Some specimens with only a slightly convex spiral side are strongly reminiscent of *G. cultrata fijicensis* Cushman, *G. johsi robusta* Bolli, and *G. cultrata multi-camerata* Cushman and Jarvis. In this respect, it is interesting to note that Banner and Blow (1960, p. 27) have suggested that *G. johsi robusta* is pseudomorphous after *G. tumida*. Still other specimens which appear to be spiro-convex are not unlike *G. cultrata panda* Jenkins. However, all these specimens can be related to *G. cf. G. tumida* because of their tumid tests and because there are specimens gradational between them and forms more like typical *G. tumida*. There are other specimens that should perhaps be referred to *G. cultrata menardii*. They have raised sutures and are less tumid than most other specimens from the Charikange Beds. However, they are con-

nected to specimens like typical *G. tumida* by transitional forms, so they have been included in *G. cf. G. tumida* too.

Banner and Blow (1960, p. 27) suggested that typical *G. tumida* did not become distinct from *G. cultrata menardii* until Upper Miocene time although representatives of it first appeared in the Upper Tortonian. Evidence from Guadalcanal supports this belief (McTavish 1963). Indeed, *G. cf. G. tumida* might be nothing more than a primitive population of *G. tumida*.

Globorotalia tumida is a tropical species. In the Pacific it is most common between temperatures of 29°C. and 31°C. and is not present in water at surface temperatures less than 19°C. (Bradshaw 1959). Beliaeva (1962, p. 10) recorded it from the Arabian and equatorial waters of the Indian Ocean where the surface-water temperature ranged from 23°C. to 28°C.

Orbulina universa d'Orbigny, 1839 — Plate 2, Fig. 22.

The specimens of *O. universa* are poorly preserved. The ultimate chamber of these specimens appears to embrace the preceding chambers completely and the test bears pore-like apertures and finer pores over its surface.

Since LeRoy's first important paper (LeRoy 1948) on the *Orbulina*-surface a large literature on the occurrence of this species has grown, and it seems widely accepted that pre-Miocene records of *O. universa* are based on misidentifications or incorrect stratigraphical information. Recent evidence (Carter 1958; Cita and Elter 1960; and Glaessner 1959, 1960) from widely separated areas of the Indo-Pacific region and Europe indicates that *Orbulina* definitely made its entry in post-Aquitanian times and suggests that it first appeared early in the Helvetian.

Pulleniatina obliquiloculata (Parker and Jones), 1862 — Plate 2, Figs. 2-4.

Specimens earlier referred doubtfully to *Globorotalia opima continuosa* Blow (McTavish 1963, p. 294) now seem more likely to be primitive forms of *P. obliquiloculata* rather reminiscent of *Globigerina nipponica* Asano. Possibly this latter species is the juvenile stage of *P. obliquiloculata* for it is markedly smaller than adult specimens of this species and is not unlike the assumed primitive forms of *P. obliquiloculata* found in the Charikange Beds. Banner and Blow (1960) believed that typical *P. obliquiloculata* ranged from the Pliocene to the Recent. However, it appears to range from late in the Tortonian (Tertiary Upper 'f') to the Recent in the Indo-Pacific region where it has been widely recorded. Its range in the Solomons is consistent with the latter view.

Sphaeroidinellopsis kochi (Caudri), 1934 — Plate 2, Figs. 25, 26, 30.

This species is rare in the Charikange fauna. It differs from *S. seminulina* in having five or six, occasionally seven, chambers in the last whorl, a more open umbilicus, arched aperture, and radially elongate chambers. Glaessner (1943, p. 69) listed *S. kochi* as a Miocene guide-fossil in the Indo-Pacific. Evidence from Venezuela (Blow 1959) and the Solomons (McTavish 1963) suggests that this species existed only during the Middle Miocene.

Sphaeroidinellopsis seminulina (Schwager), 1866 — Plate 2, Figs. 5, 8.

Sphaeroidinellopsis seminulina is the most common planktonic species in the Charikange fauna. Specimens of *S. multiloba* (LeRoy) have been included in *S. seminulina* in the belief that they represent a mature stage of this species. Accordingly, *S. seminulina* has been recognised by the three or four chambers in the last whorl with the last chamber being considerably smaller than the combined size of those preceding it. Glaessner (1943, p. 69) listed this species as a Miocene guide-fossil for the Indo-Pacific region, where it has been recorded from such widely separated areas as Borneo, Taiwan, New Zealand and Australia. In the Solomons it is present in sediments ranging in age from Burdigalian to Tortonian. Rare specimens in Upper Miocene sediments are probably reworked.

Sphaeroidinellopsis subdehiscens (Blow), 1959 — Plate 2, Fig. 1.

Banner and Blow (1960) chose *S. subdehiscens* as the type species of their new genus *Sphaeroidinellopsis*, which is distinguished from *Sphaeroidinella* by its lack of supplementary apertures. The last chamber of *S. subdehiscens* is more or less equal to the preceding two chambers and this is the feature which best distinguishes it from *S. seminulina*. However, transitional forms between these species are present in the Charikange Beds. *S. subdehiscens* is confined to the Middle Miocene and the early Upper Miocene. In the Indo-Pacific region it has been found in Taiwan, Sylvania Guyot and Papua-New Guinea. In the Solomons it is present in the Middle Miocene *Globigerina nepenthes* and *Sphaeroidinellopsis seminulina* faunas and small numbers have been recognised in the basal part of the Upper Miocene *Globigerina dutertrei* fauna.

Age Significance

If considered alone, the larger foraminifera from the Charikange Beds samples would be thought to comprise a Burdigalian or an early Vindobonian assemblage. The following species are regarded as essentially Burdigalian (— Tertiary f₁₋₂): *Lepidocyclina* ("Multilepidina") *suvaensis*, *Miogypsina polymorpha*, *Cycloclypeus* (*Katacycloclypeus*) *martini*, *Lepidocyclina* (*Nephrolepidina*) *japonica*. A Vindobonian age is suggested by the presence of *L. (N.) martini* and *C. (C.) indopacificus*; both these species may be found in older sediments of Burdigalian age. The suggestion of a late Burdigalian to early Vindobonian age is a compromise and not a studied calculation; it probably exceeds the limits of refinement possible with larger foraminifera during this part of the Tertiary. So far as the planktonic foraminifera are concerned the abundance of species of *Sphaeroidinellopsis*, especially *S. seminulina*, with species of *Globorotalia quadrina*, indicate that this association should be correlated with the *Sphaeroidinellopsis seminulina* fauna as it is expressed in the Malaita Group in the Solomon Islands. This Malaitan fauna was correlated in turn (McTavish 1963, pp. 68-69) with the *Sphaeroidinella seminulina* zone of Venezuela (see Blow 1959) which is shown by Blow and Banner (1962, p. 137) as spanning the Tortonian-Sarmatian boundary.

The older age limit of this zone has not yet been established and so it would be too specific at this stage to restrict the Malaitan *Sphaeroidinellopsis seminulina* fauna to the Tortonian, a younger age than is indicated by the larger foraminifera, although the stratigraphic position of the Charikange samples would support this assignment. We have been content therefore to describe this association as simply Vindobonian. Nevertheless, if it is indeed true that the foraminifera preserved in the samples were contemporaneous, then the possibility remains that the following species of larger foraminifera survived into Tortonian time: *Lepidocyclina* ("Multilepidina") *suvaensis* (Whipple), *Lepidocyclina* (*Nephrolepidina*) *japonica* Yabe, *Miogyopsina polymorpha* (Rutten), *Cycloclypeus* (*Katacycloclypeus*) *martini* Van der Vlerk, and *Operculina complanata japonica* Hanzawa.

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